EME with JT65

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Most readers of this column already know about WSJT, a free computer program[1,2] that can greatly enhance your station's capabilities for making distant VHF/UHF contacts. The program was designed with meteor scatter and Earth-Moon-Earth (EME) communication especially in mind. Anyone who has attempted such QSOs knows they are not easy at amateur power levels — which of course is one reason why they can be so much fun.

Successful EME stations, in particular, require the very best of amateur engineering. It's always a stretch: we strive for every possible dB of antenna gain and transmitted power, while minimizing our feedline losses and receiver noise figures. The necessary hardware can be large and complex, and some of it is expensive. Optimizing the various parts of our stations while minding the budget is a game that all EME enthusiasts must learn to play.

These days, not all good engineering involves hardware — and that's where WSJT and its operating mode JT65 come in. The JT65 transmission protocol uses state-of-the-art message encoding with powerful error-correcting features, coupled with highly efficient modulation based on a constant-envelope waveform and 65-tone frequency-shift keying. The combination is much more effective for EME than Morse code and on-off keying. Together with well optimized decoding algorithms, it enables JT65-equipped stations to make QSOs at signal levels some 10 to 15 dB below the minimum required for "ear and brain" CW communication. This huge advantage brings EME capability within reach of a much wider range of stations. Perhaps best of all, WSJT is designed to facilitate contacts between human operators, not between computers. The internet does the computer link so easily that we don't even pause to think about it; JT65 EME contacts, on the other hand, are thrilling and fun.

Over the past year, JT65 has been used to make at least several thousand EME QSOs on bands from 50 to 1296 MHz. On 2 meters, the most popular EME band worldwide, 300 Watts and a good yagi pointed at the Moon can enable you to work dozens of other EME stations, anywhere in the world. Somewhat larger stations will find *hundreds* of workable QSO partners, and the number of active stations is increasing all the time.

JT65 was designed to work efficiently with the existing standards and conventions for EME contacts. It starts by ensuring that its transmitted messages are compact and efficient. On users' computer displays, the exchanges in a JT65 EME QSO typically look something like this:

1.	CQ VK7MO QE37	
2.		VK7MO K1JT FN20
3.	K1JT VK7MO QE37 OOO	
4.		RO
5.	RRR	
6.		TNX REX 73 GL
7.	FB SIG JOE 73	

[1] J. Taylor, K1JT, "WSJT: New Software for VHF Meteor-Scatter Communication," *QST* December 2001, pp. 36-41.

[2] J. Taylor, K1JT, "JT44: New Digital Mode for Weak Signals," *QST* June 2002, pp. 81-82

Transmissions 1–3 use the basic JT65 message format of two callsigns, a grid locator, and an optional "OOO" signal report. (CQ or QRZ can be substituted for the first callsign.) After callsigns have been exchanged, transmissions 4 and 5 complete the QSO by sending a return signal report and acknowledgments that all necessary information has been received. Transmission 6 lets VK7MO know that his "RRR" transmission was received, and further conversational chit-chat may follow. Aside from the embellishment of exchanging grid locators, this model QSO closely follows standard EME practice for CW QSOs. JT65 transmissions start at the top of each UTC minute, so if copy is good a minimal QSO can be completed in 5 or 6 minutes.

Detailed operating instructions are provided in the *WSJT User's Guide*[3]. You can learn the essential operating skills by reading the manual and making a few practice QSOs, perhaps using extremely low power or a difficult tropospheric path to ensure that signals are barely audible, or even sub-audible. As you accumulate experience you will see your JT65 skills continue to improve, and your rate of successful contacts should rapidly climb.

Unlike Morse code, JT65 does not transmit messages character by character. The forward error correction (FEC) built into every encoded message makes it highly probable that JT65 messages will be received in their entirety, or not at all. The decoder does occasionally make mistakes, most commonly because a birdie or other interfering signal is present. In such cases errors in the falsely decoded messages are large, easy to recognize, and readily rejected by the operator. You will never see broken callsigns with a few missing or incorrect characters, or message fragments of any sort. There is no chance for the letter O or R in a callsign to be confused with a signal report or an acknowledgment, or for a fragment of a callsign like N8CQ or a grid locator like EM73 to be misinterpreted.

Just how does JT65 work, and where does its mysterious 10 – 15 dB of "gain" over CW originate? The answer lies in the use of coding and modulation explicitly designed to optimize exchanges of short messages at a low but acceptable throughput, around 0.3 characters per second. Standard JT65 messages are compressed or "source encoded" using a clever scheme proposed some years ago[4] by W3IWI and KA9Q, enabling two callsigns and a grid locator to be transmitted with just 71 bits. In JT65, a 72nd bit serves as a flag to indicate that the message consists of arbitrary text (up to 13 characters) instead of callsigns and a grid locator. Special formats allow other information such as callsign prefixes (e.g., ZA/PA2CHR) or numerical signal reports (in dB) to be substituted for the grid locator. The aim of source encoding is to compress the common messages used for EME QSOs into a minimum fixed number of bits.

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[3] See http://pulsar.princeton.edu/~joe/K1JT/Documentation.htm to download the *WSJT User's Guide*. Thanks to a number of WSJT users, the manual is available in French, Italian, Japanese, Russian, and Serbian, in addition to English.

[4] Clark, T. W3IWI, and Karn, P., KA9Q, "EME 2000: Applying Modern Communications Technologies to Weak Signal Amateur Operations," *Proc. Central States VHF Society,* 1996.

After compression, each 72-bit message is augmented with 306 error-correction bits. This process is defined by a mathematical code known as RS(63,12) — a so-called "Reed Solomon code" — which converts 72-bit user messages into sequences of 63 six-bit "channel symbols" for transmission. Every sequence used in the code differs from every other one in at least 52 of the 63 symbols — which, in a nutshell, is why the code is so powerful. By actual measurement, the full and exact transmitted message has a high probability of being received, even if the average key-down SNR is as low as 2 to 6 dB in 2.7 Hz bandwidth (roughly –28 to –24 dB in 2500 Hz, the conventional reference bandwidth used in WSJT).

Like the traditional CW procedures for EME, JT65 uses special signal formats to convey a few frequently used messages in a robust and efficient way. Three such messages are presently defined, conveying the messages "RO", "RRR", and "73". Instead of keying a single-frequency carrier on and off according to a pattern like di-dah-dit, dah-dah-dah, …, JT65 sends "RO" by transmitting two alternating tones with specified frequencies and switching rate. Such waveforms are easy to recognize and to distinguish from one another, as well as from "normal" JT65 messages. Indeed, as many users have discovered, the shorthand messages of JT65 are readily decodable by human operators using sight and sound, as well as by a computer.

JT65 uses one-minute T/R sequences and requires tight synchronization of time and frequency between transmitter and receiver. Typical amateur equipment cannot accomplish this task with enough accuracy in open-loop fashion, so JT65 signals carry their own synchronizing information. A pseudo-random "sync vector" is interleaved with the encoded information symbols. It allows calibration of relative time and frequency errors with accuracies of about 0.03 s and 1.5 Hz, respectively, thereby establishing a rigorous framework within which the decoder can work. In addition, it enables the averaging of successive transmissions so that decoding can be accomplished even when signals are too weak for success in a single minute. The synchronizing signal is so important that (except in shorthand messages) half of every transmission is devoted to it.

A JT65 transmission is divided into 126 contiguous time intervals, each of length 0.372 s (4096 digitized samples at 11025 samples per second). Within each interval the waveform is a constant-amplitude sinusoid at one of 65 pre-defined frequencies, and frequency changes between intervals are accomplished in a phase-continuous manner. A transmission nominally begins at $t = 1$ s after the start of a UTC minute and finishes at $t = 47.8$ s. The synchronizing tone is at 1270.5 Hz, and is normally sent in each interval having a "1" in a pre-defined pseudo-random sequence of 0s and 1s known to both transmitter and receiver. This sequence has the desirable mathematical property that its normalized autocorrelation function falls from 1 to nearly 0, for all non-zero lags. As a consequence, it makes an excellent synchronizing vector.

Encoded user information is transmitted during the 63 intervals not used for the sync tone. Each channel symbol generates a tone at frequency $1275.8 + 2.6917\,Nm$ Hz, where N is the value of the six-bit symbol, $0 \le N \le 63$, and m is 1, 2, or 4 for JT65 sub-modes A, B, or C (see the *WSJT User's Guide* for further details on the sub-modes). The signal report "OOO" is conveyed by reversing sync and data positions in the transmitted sequence. Shorthand messages dispense with the sync vector and use intervals of 1.486 s (16,384 samples) for the alternating tones. The lower frequency is always 1270.5 Hz, the same as that of the sync tone, and the frequency separation is $26.92\,nm$ Hz with $n = 2, 3, 4$ for the messages RO, RRR, and 73.

As a teaser, let me offer two examples of what can be done with JT65 on the 144 MHz EME path. Joop Mutter, PA0JMV, has made a special game of working the smallest stations he can contact by EME. His list now includes 39 stations at ERP levels (transmitted power times antenna gain) between 1.5 and 8 kW. More than half of the stations on his list run less than 200 Watts and use one or two yagis. Joop has an excellent EME setup, but it is hardly in the super-station category: he runs 1.5 KW to a pair of 16 element yagis mounted in his garden, and positioned by hand.

Bill Davis Jr., K0AWU, joined the JT65 EME fun in February 2005, just two weeks before I write these words. It was mid-winter in Minnesota (see picture), so Bill erected a simple mast in his driveway, guyed it to some handy anchoring points, and put a 13 element yagi on top. He also uses the "armstrong" method to point it at the moon. With this temporary lash-up and running 700 Watts, Bill has worked 44 different EME stations, including 22 DXCC entities, in two weeks.

Working stations that you can't hear (or can hardly hear) takes some getting used to. New operating procedures need to be developed that will make it easier for stations to find each other and start a QSO. At present, a majority of JT65 EME QSOs originate when someone posts a CQ notice on the JT65 EME Link, http://www.chris.org/cgi-bin/jt65eme, or by making a real-time schedule there. Schedules are a good way to start, and if you need coaching the internet chat pages are excellent places to get it. However, to ensure that your QSOs are legitimate, be sure to suspend any use of the reflector (and any other non-EME means of communication) for any contact-related information while the QSO is in progress. It is considered very bad form, and invalidates your QSO as a true EME contact, if you convey something like "I have copied both calls, I'm now sending my report" via some other means while your QSO is in progress.

It will be helpful for the community of EME users to give collective thought to operating procedures and band-plan issues relating to JT65. On 2 meters, most JT65 activity is found between 144.100 and 144.160. Agreement on a small range of calling frequencies for CQs, such as 144.120 – 144.130, could provide a significant boost to random (as opposed to scheduled) operation. Japanese users generally transmit JT65 below 144.100, and other national or regional issues may be important. EME activity on 6 meters seems to center around 50.190, and I believe there is some concentration toward 432.044 and 1296.044 on the UHF bands. I encourage wide discussion of such questions, and hope that a consensus can be achieved.

Finally, I should briefly mention FSK441, the popular WSJT mode designed for making meteor scatter contacts. Unlike JT65, which transmits slowly and works with extremely weak signals, FSK441 transmits at the high rate of 147 characters per second to take advantage of fraction-of-a-second reflections from the ionized trails of meteors. Meteor scatter QSOs in the 800 – 2000 km range can made be on the VHF bands at any time, using FSK441. Such contacts are a excellent way to get your feet wet, before trying EME with JT65.

WSJT can be freely downloaded from http://pulsar.princeton.edu/~joe/K1JT, and from the European mirror site http://www.dk5ya.de/.


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El /Az control, move gas can!